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OPTIMISATION OF WIRE EDM PROCESS PARAMETERS ON D3 TOOL STEEL USING PRINCIPAL COMPONENT ANALYSIS

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ABSTRACT

Wire electrical machining is an extremely potential electro thermal process that is use to machine material of any hardness, strength with very close tolerance. WEDM can also machine precise, complex and irregular shapes with high degree of accuracy and fine surface finish. The aim of the present research work is to optimize the machining parameter of wire electrical discharge machining (WEDM) for multiple performance characteristics on D3 tool steel using principal component analysis (PCA). The experiment work is carried out on sprint cut Elektra wire cut electric machine (ELPLUS 40A DLX) based on Taguchi's L9 orthogonal array (OA) with combinations of four inputs machining parameters viz. pulse on time, pulse off time, peak current and servo feed. The performance response is surface finish, material removal rate and wire wear ratio. Principal component analysis has been accumulated to compute a multi-response performance index (MPI). Analysis of variance (ANOVA) is also carried out and it is found that Ton is most significant factor where as Ip is most effective parameter affecting material removal rate, surface roughness and wire wear ratio. Optimal parameters of wire EDM is found out for maximization of material removal rate and minimization of surface roughness and wire wear ratio. Finally, the optimal result is verified through confirmation experiment and it is found that the improvement in material removal rate is 27.03%, where as the improvement percentage for surface roughness is 18.51 and for wire wear ratio 1.03%.

KEYWORDS: Wire EDM, D3 Tool Steel, Principle Component Analysis, Taguchi's, ANOVA, Material Removal Rate & Surface Finish

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Original Article

INTRODUCTION

Wire electrical discharge allowed success in the production of newer materials, especially for the aerospace and medical industries. Using WEDM technology, complicated cuts can be made through difficult-to-machine electrically conductive components. WEDM is a thermo-electrical process in which material is eroded from the work piece by a series of discrete sparks between the work piece and the tool (wire electrode) separated by a de-ionized water which is circulated to flush away debris. The principle of Wire EDM is shown in figure 1. The cutting pattern is usually CNC controlled. With a wire EDM machine, if a cutout needs to be created, an initial hole must be first drilled in the material, and then the wire can be fed through the hole to complete the machining.[1] Though it is widely used nontraditional manufacturing process in industries it is difficult to machine the materials like OHNS, Titanium, Nimonics, Zirconium etc. with intricate shapes so the selection of optimum machine setting or cutting parameters in WEDM is an important step. Improperly selected parameters may result in serious consequences like short circuiting of wire and wire breakage, imposing certain limit on cutting speeds and reducing productivity. To avoid these consequences it becomes necessary to optimize the machining parameters of

WEDM. This optimization is done with the help of mathematical modeling and Evolutionary algorithm.[2]

In this paper an attempt has been made to optimize the Wire EDM for the multiple responses viz. Wire wear ratio, material removal rate and surface roughness using principal component analysis. Four process parameter viz pulse on time, pulse off time, peak current and servo feed are consider for the study. D3 tool steel is used as a work piece material. Experiments are conducted based on L9 orthogonal array (OA). Analysis of variance is also carried out In order to find the significance factor and their interactions.

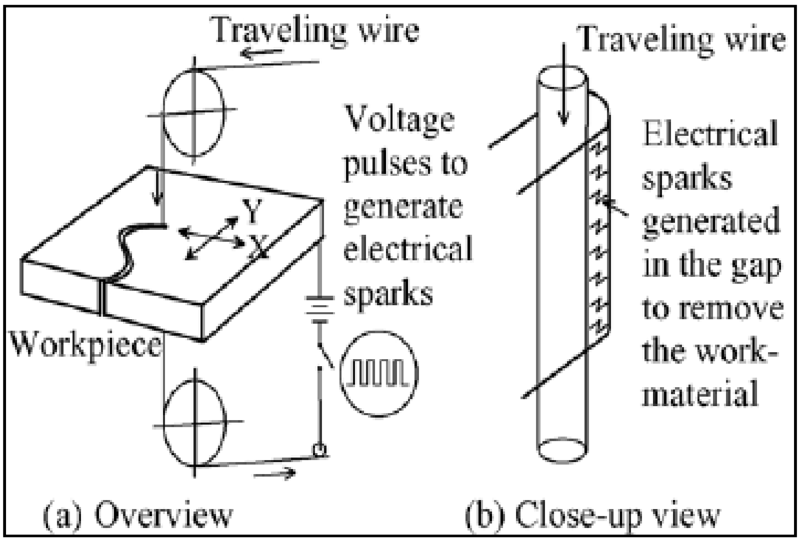

Figure 1: Principle of Wire EDM [3]

EXPERIMENTAL SETUP

The experiment work is carried out in sprint cut ElEKTRA wire cut electric machine (ELPLUS 40A DLX) as shown in Figure 2 of D3 tool steel by varying machining parameters. The sprint cut wire electric discharge machine consist of a power supply unit, machine tool and dielectric supply unit.

Figure 2: Sprint Cut Wire Electric Discharge Machine

The work material in this experiment was AISI D3 tool steel. The chemical composition of the D3 tool steel is shown in Table 1. A commercial available D3 plate with 205x178x10mm was used for performing WEDM experiment. The work piece first get polished and then hardened for better surface finish and productivity. A commercially available zinc coated brass wire of diameter 0.25mm is used as electrode material.

Table 1: Chemical Composition of AISI D3 Tool Steel (wt)

Material	C	Cr	Mn	Ni	Mo	V	Si
AISI D3	2.05	11.10	0.598	0.065	0.042	0.055	0.498

Selection of Orthogonal Array and Parameter Assignment

For the present experimental work the four process parameters each at three levels have been decided. The selection of factors was based on the manual [4] and the suggestion from handbook [5] the recommended by the machine manufacturer. There should be three levels of process parameters to reflect the true behavior of response parameter. Table 2 shows four process parameter with three levels and Table 3 shows fixed parameters.

Table 2: Process Parameter and their Levels

Parameter	Symbol	Unit	Levels		
			L_1	L_2	L_3
Pulse on time	Ton	μs	116	120	124
Pulse off time	Toff	μs	58	60	62
Peak current	Ip	A	170	200	230
Servo feed	Sf	V	2110	2120	2130

Table 3: Fixed Parameters

Wire	Zinc Coated Brass Wire of Diameter 0.25mm
Work piece	Die plate for Dairy creamer cup cover
Di electric fluid	De-ionized water
Conductivity of Di-electric fluid	20 mho

In the present experiment there are three levels and four factors (process parameter). It mean the total number of experiments become 81 (3^4). The design of orthogonal array is formed for OA L9 (3^4) using Mintab16 software. This software has directly given the best fit L9experiment are reduced to nine instead of eighty one. Table 4 shows the taguchi orthogonal array L9, using this values experimentation is performed.

Table 4: Taguchi Orthogonal Array L9

Run No.	Ton(μs)	Toff(μs)	Ip(A)	Sf(V)
1	116	58	170	2110
2	116	60	200	2120
3	116	62	230	2130
4	120	58	200	2130
5	120	60	230	2110
6	120	62	170	2120
7	124	58	230	2120
8	124	60	170	2130
9	124	62	200	2110

METHODOLOGY - PRINCIPLE COMPONENT ANALYSIS

Principal component analysis (PCA) is one of the most popular multivariate statistical methods. It was first

introduced by Pearson (1901) [6] and later developed by Hotelling (1933) [7]. PCA is used to explain the variance-covariance structure through linear combination of the original variables. Assume that there are p component to represent the system variability. Using PCA, this variability can be explained by a small number q ($q \leq p$), of principal components, i.e., q principal components will account for the variance in the original p variables. Let, Y1, Y2…, Yp be a set of variables. Through the PCA, the following q uncorrelated linear combinations can be obtained:

$$\Omega_1 = \alpha_{11}\, Y_1 + \alpha_{12}\, Y_2 \ldots..+ \alpha_{1p}\, Y_p$$

$$\Omega_2 = \alpha_{21}\, Y_1 + \alpha_{22}\, Y_2 \ldots..+ \alpha_{2p}\, Y_p$$

$$\Omega_q = \alpha_{q1}\, Y_1 + \alpha_{q2}\, Y_2 \ldots..+ \alpha_{qp}\, Y_p$$

Where $\alpha^2_{q1} + \alpha^2_{q2} + \ldots\ldots + \alpha^2_{qp} = 1$. Further, Ω_1 is called the first principal component, Ω_2 is the second principal component and so on. The coefficients of q^{th} component are the elements of the eigenvector corresponding to q^{th} Eigen value.

Assuming that there is p response and m experimental trial, the procedure for principal component analysis is as follow:-

Step1: Compute the S/N ratio for each response.

Taguchi categorized the response variables into three different types, e.g. the larger the better, the smaller the better and the nominal the best. The S/N ratio is represent as η therefore the formula for j^{th} response in i^{th} trial is as follows:-

For larger the better, $\eta_{ij} = -10 \log10 \left(\frac{1}{n} \sum_{k=1}^{n} \frac{1}{y^2_{ijk}}\right)$

For smaller the better, $\eta_{ij} = -10 \log10 \left(\frac{1}{n} \sum_{k=1}^{n} y^2_{ijk}\right)$

For the nominal the best, $\eta_{ij} = -10 \log10 \left(\frac{\mu^2}{\sigma^2}\right)$

Where $\mu = \frac{1}{n} \sum_{k=1}^{n} y_{ijk}$, $\sigma 2 = \frac{1}{n-1} \sum_{k=1}^{n} (y_{ijk} - \mu)2$, n represents the number of repeated experiment, ηijk is the S/N ratio of jth (j=1,2,….,p) response variable in the ith (i=1,2,…,m) experimental trial and yijk is the experimental value of jth response variable in ith experiment at kth test.

The S/N ratio measure how the response varies relative to the target value under different noise conditions. Depending on the required objective characteristics, there are three Type of S/N ratio the lower the better, the higher the better and the nominal the better. While material removal rate is a larger the better type response variable, wire wear ratio and surface roughness is a smaller the better type response variable. Table 5 shows the result in terms of signal to noise ratio for MMR, WWR and Ra value for all nine experiments.

Table 5: S/N Ratio for Ra, MMR & WWR

Ex. No	Ton (μs)	Toff (μs)	Ip(A)	Sf(V)	Ra (μm)	MMR (mm^3/min)	WWR	S/N Ratio		
								Ra (μm)	MMR (mm^3/min)	WWR
1	1	1	1	1	1.89	185.292	0.979	-5.529	45.357	0.184
2	1	2	2	2	2.51	192.282	0.977	-7.993	45.678	0.202
3	1	3	3	3	2.49	185.292	0.980	-7.923	45.357	0.175
4	2	1	2	3	2.32	248.562	0.985	-7.309	47.908	0.131

Table 5: Contd.,

5	2	2	3	1	2.74	237.001	0.984	-8.755	47.495	0.140
6	2	3	1	2	2.45	199.825	0.981	-7.785	46.013	0.166
7	3	1	3	2	2.68	299.737	0.987	-8.562	49.534	0.113
8	3	2	1	3	2.61	242.644	0.985	-8.332	47.699	0.131
9	3	3	2	1	2.38	261.309	0.985	-7.531	48.343	0.131

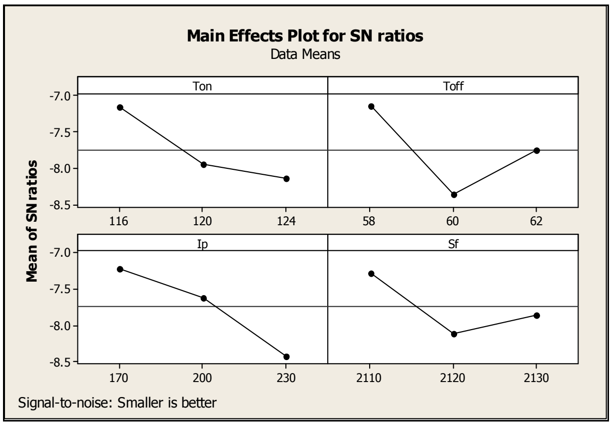

Figure 3: Effect of Process Parameter on Surface Roughness

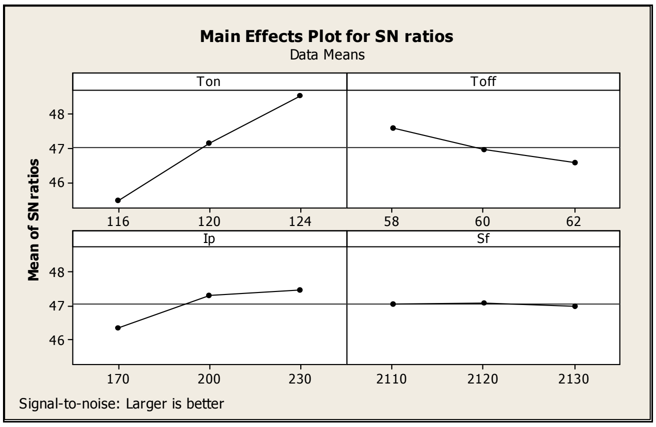

Figure 4: Effect of Process Parameter on MRR

Figure 3 shows the S/N ratio plots for the surface roughness. Surface roughness is the lower the better type quality characteristics. from Figure 3 it can been seen that the third level of Ton (A_3),second level of T off (B_2), third level of Ip (C_3) & second level of servo feed (D_2) provide minimum value of surface roughness.

Figure 4 shows the S/N ratio plots for the material removal rate. As MRR is the larger the better type quality characteristics. from figure 4 it can been seen that the third level of Ton (A_3),first level of T off (B_1), third level of Ip (C_3) & first level of servo feed (D_1) provide maximum value of MRR.

Figure 5 shows the S/N ratio plots for the Wire wear ratio. As WWR is the lower the better type quality characteristics. from figure 5 it can been seen that the first level of Ton (A_1),third level of T off (B_3), first level of Ip (C_1) & second level of servo feed (D_2) provide minimum value of WWR.

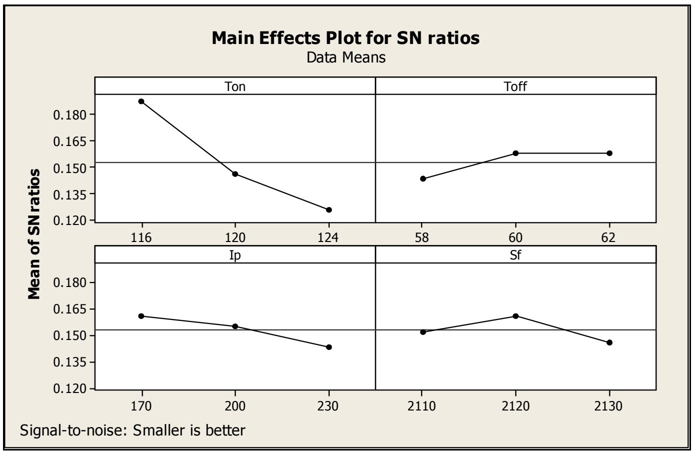

Figure 5: Effect of Process Parameter on WWR

Step 2: Transform the S/N ratio value for each response into (0,1) interval, using formula

$Y_{ij} = \frac{\eta_{ij} - \eta_j^{min}}{\eta_j^{max} - \eta_j^{min}}$ and the derived value are tabulate in Table 6

Table 6: Scaled S/N Ratio Value

EXP.NO	Ton	Toff	Ip	Sf	S/N ratio			Scaled S/N RATIO		
					Ra	MRR	WWR	Ra	MRR	WWR
1	1	1	1	1	-5.529	45.357	0.184	1	0	0.799
2	1	2	2	2	-7.993	45.678	0.202	0.236	0.077	1
3	1	3	3	3	-7.923	45.357	0.175	0.448	0.610	0.199
4	2	1	2	3	-7.309	47.908	0.131	0.448	0.610	0.199
5	2	2	3	1	-8.755	47.495	0.140	0	0.511	0.298
6	2	3	1	2	-7.783	46.013	0.166	0.301	0.156	0.598
7	3	1	3	2	-8.562	49.534	0.113	0.059	1	0
8	3	2	1	3	-8.332	47.699	0.131	0.130	0.560	0.199
9	3	3	2	1	-7.531	48.343	0.131	0.379	0.714	0.199

Step 3: Perform the PCA on the basis of computed data, Y_{ij}

In this present work Mat-lab is used to find out Eigen value and Eigen vector.

Table 7: Eigen Values and Eigen Vectors

Principal Component	Eigen Value	Eigen Vector
First	0.1577	[0.0902, 0.885, 0.456]
second	0.7060	[0.7260, 0.255, -0.638]
Third	2.136	[0.6818, -0.389, 0.619]

Step 4: Determine the number of Principal components, which can be used to represent the original responses.

The Components with Eigen value greater than one can be chosen to replace the original responses for further analysis. usually, the value of q is one. It can be noted from the table the Eigen value for the third principal component is only greater than one.

Step 5: compute q^{th} principal component corresponding to i_{th} trial.

The multi-response performance index (MRPI), i.e., the value of the third principal component for i^{th} (i= 1, 2 …., 9) trial can be computed using the following equation:

$$MRPI = a_{31}Y_{i1} + a_{32}Y_{i2} + a_{33}Y_{i3}$$

$$MRPI = 0.6818\,Y_{i1} - 0.389\,Y_{i2} + 0.619\,Y_{i3}$$

Where Y_{i1}, Y_{i2} and Y_{i3} represent the scaled S/N ratio values for the responses R_a, MRR and WWR respectively, at i^{th} trial. The S/N ratio and MRPI values for all the responses in 9 trial are listed in Table 7.

Table 8: MRPI Values

EXP.NO	Ton	Toff	Ip	Sf	MRPI
1	1	1	1	1	1.176495
2	1	2	2	2	0.750001
3	1	3	3	3	0.191179
4	2	1	2	3	0.191179
5	2	2	3	1	-0.01403
6	2	3	1	2	0.514949
7	3	1	3	2	-0.34835
8	3	2	1	3	-0.00556
9	3	3	2	1	0.103856

Step 6: Determine the optimal factor-Level combination.

The ANOVA is carried out on these multi-response performance index (MRPI) values. The ANOVA results are shown in table. It is observed from table 8 that factor Ton i.e. pulse on time is the most important process parameter. The value of F-statistics for peak current are greater than two implying that these factor are also having significant impact on the MRPI value.

Table 9: ANOVA on the MRPI Values

Source	DF	Sum of Square	Mean Square	F Ratio	Contribution %
Ton	2	0.946	0.473	7.08	57.16
Toff	2	0.014	0.007	0.11	0.84
Ip	2	0.592	0.296	4.43	33.95
Sf	2	0.133	0.066	*	8.036
Error	0				
Total	**8**	**1.687**	**0.842**		**100**

Table 10: Level Averages on the MRPI Values

Factor	level 1	level 2	level 3
Ton	0.705892	0.230701	-0.08335
Toff	0.339774	0.24347	0.269995
Ip	0.56196	0.348345	-0.05707
Sf	0.422108	0.305533	0.125598

RESULTS

Table 9 summarizes the level averages on the MRPI values and the plots of these level averages are shown in figure 5.13.larger value of the MRPI implies better quality. Consequently, the optimal condition for factors Ton, Toff, Ip and Sf can be set as A_1 B_1 C_1 D_1.

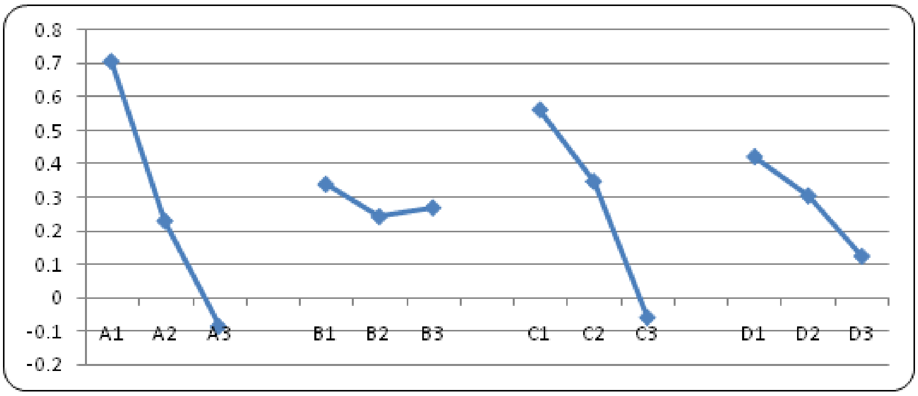

Figure 9: MRPI Values at Different Factor Levels

- Ton is a most significant factor.
- Ip is also a effective parameter.
- T off and S f less effective.
- Optimum experiment levels is

Table 11: Result Table

Parameter	Ton	T off	Ip	Sf
Level	116	58	170	2110

CONFIRMATION EXPERIMENT

The final step in the research work is to do confirmation test. The purpose of the confirmation test is to validate the conclusion drawn during the analysis phases. In addition, the confirmation tests needs to be carried out in order to ensure that the theoretical predicted optimal parameters are acceptable or not. The confirmation test with optimal process parameter is performed on wire cut EDM for D3 tool steel at level A_1 (Ton 116 µs) B1 (Toff 58 µs), C_1(Ip 170 A), D_1 (Sf 2110 V) and its gives material removal rate 235.391 mm^3 /min, surface roughness 1.54 µm and wire wear ratio 0.969. Percentage improvement for surface roughness is 18.51%, material removal rate 27% and wire wear ratio 1.03%

Table 12: Confirmation Result

Response Variable	Optimal level A1,B1,C1,D1		Percentage Improvement
	Predicted Value	Experimental Value	
Material Removal Rate	185.292	235.391	27%
Surface roughness	1.89	1.54	18.51%,
Wire wear ratio	0.979	0.969	1.03%

CONCLUSIONS

The multi response of a WEDM process can be effectively optimized using the principal component analysis method. However, there is no need for any input from engineers during analysis of the experimental data in the principal component method. The principal component analysis method reduce the uncertainly and complexity of engineers judgments associated with taguchi method and it give better optimization results.

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